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ECONOMICS AND LEGAL ISSUES

THE ECONOMICS OF URBAN STORMWATER MANAGEMENT

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INTRODUCTION

Flooding from stormwater runoff has long been recognized as a hazard of living in areas near streams. For the most part, actions to reduce the likelihood and magnitude of flood damage have focused on providing protection at the site of damage. Implicit in these flood protection programs is the belief that flooding is a natural phenomenon that cannot be dealt with effectively by other means.

Recent research findings have led engineers—and now economists—to view urban stormwater management from an entirely different perspective. The pollutant loads contributed to urban watercourses by stormwater runoff, long thought to be negligible, appear instead to be major sources of water quality impairment. As a consequence, current federal legislation requires that nonpoint source pollution be evaluated in areawide water quality planning. The flooding problem also has taken on new dimensions in light of the discovery that urbanization can significantly increase peak flows and thereby exacerbate flood damage downstream. Public policy reaction to this finding has been rather slow to materialize.

The essential economic problem raised by these findings is that changes in upland/upstream land use impose external costs in the form of increased pollution and flood damage risk upon downstream residents. Upland/upstream residents and developers have no incentive to change the practices that cause the problem since the consequences of the increased runoff are borne by others—by the downstream residents themselves, and by the general taxpayer if traditional governmental protection programs are used to lessen the damage downstream. Thus, barring fundamental change in the nature of stormwater management, we should expect flooding and water

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quality problems to become steadily worse as upstream development proceeds.

The purpose of this paper is to outline the major features of an effective stormwater management system that takes explicit account of the important externality aspects we now recognize as significant contributors to urban runoff problems. Perhaps the most important finding reported here is that these problems are in large measure a consequence of individually rational actions by well-meaning firms and households. Before turning to specifics, we must first explore the basic economic principles by which potential policy actions are judged.

Since both the damages suffered by victims of flooding and water quality impairment and the measures taken to reduce or avoid these damages are costly, the most effective policy is the one that minimizes the sum of damage costs (D) and treatment or mitigation costs (T) to all affected parties. Different policy actions will generally imply different trade-offs among T and D. Given that these trade-offs exist, it is extremely unlikely that the optimal amount of damage is zero; the cost of complete protection will in general be greater than its value to those protected. To minimize total costs, mitigation measures should be carried out just up to the point at which an additional dollar of T returns exactly one additional dollar of benefits in the form of reductions in D. It is in society's interest to carry out treatment in the most economical place possible, using the most efficient techniques available. The question of who pays for mitigation is an entirely separate issue. It is important to note that the mitigation costs borne by the governmental agency in charge of runoff policy are not necessarily the full social costs of the programs that the agency undertakes. For example, nonstructural controls that have the effect of removing some land from possible development have very low governmental costs, but the income lost to the developer as a result of the control program is a cost to society, just as it would be if the land were purchased directly by the government.

We shall now consider some aspects of the stormwater management problem in greater detail.

STORMWATER RUNOFF: PHENOMENON OF NATURE OR EXTERNALITY?

Most pollution is a byproduct of human activity. Firms and households dispose of wastes from their production and consumption activities by releasing these wastes into the environment. If the quantity of wastes discharged is great relative to the environment's capacity to assimilate such discharges, society suffers a decline in environmental quality. The environmental costs of human activities differ from other costs of production or consumption (such as labor, materials, and capital costs), however, in that these costs are largely borne not by the producer but by others. In effect, then, polluters can disregard the external costs that their pollution generates for other users of the environment. From the viewpoint of society as a whole, pollution damages are real costs and they should be considered as such by polluters when they make their production or consumption decisions. For this reason, public policy toward point sources of pollution has been focused on forcing those responsible to reduce their discharges. Since it is generally cheaper for polluters to control their emissions than for other users of the environment to treat the pollution they experience, this is usually a cost-effective pollution-control policy.

Stormwater pollution from nonpoint sources can also be seen as an externality problem. Human activities are responsible for leaving on the ground large amounts of organic matter, fertilizers, pesticides, ice control salts, etc., to be picked up by stormwater runoff. In addition, construction activities (particularly land clearance) lead to soil erosion, which greatly increases the volume of suspended solids picked up by runoff and deposited into receiving watercourses. Stormwater pollution control, like point source control policy, should focus on altering the behavior of those whose activities cause the problem as long as it is cost effective to do so. The most efficient policy instruments for accomplishing this will depend on the nature of the pollution-generating activities. The components of effective nonpoint source control policy are discussed more fully in the next section.

As was noted in the introduction, the externality component of urban flooding has until recently been ignored by policymakers. Since natural forces are responsible for rainfall, it has been assumed that the ensuing runoff and flooding are also natural phenomena. Protection from damage has thus been the major goal of flood control policy, with firms and households in flood-prone areas (and the general public through federal and local flood control agencies) having the responsibility for solving the problem. We now know that development in a watershed may cause significant changes in the runoff pattern produced by any given storm. Urbanization leads to increases in the natural gradient of the land so that individual parcels will drain quickly, to the removal of natural vegetative cover, and to the replacement of permeable soils by impervious streets, parking lots, and buildings. Such changes increase both the volume and speed of runoff, causing much higher peak flows in receiving watercourses. The capacity of these streams is taxed to a greater extent, and the likelihood of flood damage downstream is increased. In short, urban development generates external costs in the form of increased runoff and flood damage risk to downstream communities. Flooding is thus the result of both human activity and natural forces.

The externality aspect of stormwater runoff is the fundamental economic problem that must be addressed in a comprehensive management program. The key to understanding the resulting policy complexities is that upstream residents and developers have no economic incentives to alter their runoff-increasing and quality-degrading behavior, since the adverse consequences of these activities are faced by others. A profit-seeking developer is concerned only with the costs and benefits that he personally incurs; he disregards any other costs that his actions may impose on downstream residents. Developers will not voluntarily reduce or clean up their runoff because it is not in their interest to do so. Runoff controls are personally costly for them, and the benefits of these controls will accrue to the protected downstream residents.

Since market prices reflect only private costs and exclude external costs, developments will be less expensive if runoff controls are not undertaken. As a consequence, more upstream development will take place than if upstream communities were forced to take into account the external costs they impose on others. From the viewpoint of society as a whole, too much (and the wrong kind of) upstream development will occur, and too much flooding and pollution will be experienced downstream (i.e., for some upstream development the costs *to all affected parties* will exceed the benefits they receive even though development is privately profitable for the firm which undertakes it).

The most important policy implication of viewing flooding as an externality problem is that the focus of control must be shifted from controlling flooding downstream to reducing runoff upstream. The present emphasis on downstream controls is misplaced because it focuses concern away from the changes in upstream land uses that are the major source of increases in peak flows. Downstream flood controls based on the erroneous belief that rainfall-runoff patterns are fixed by nature (and are thus unchanging over time) will in fact provide less and less protection as upstream urbanization takes place and modifies the runoff pattern in a watershed. For example, in the 1950s the lower portion of White Oak Bayou in Houston was channelized and lined with concrete to protect nearby residents from the Standard Project Flood of approximately 18 inches of rain. Because of unregulated upstream urbanization since the completion of this structural control project, however, the concrete channel now provides protection against only the 30-year storm of about 11½ inches. Continued unregulated upstream development in the watershed is expected to lower the level of protection still further.

A stormwater management program that is to be effective not only in the present, but also in the future as upstream development occurs, must incorporate the most cost-effective mix of upstream runoff reduction and downstream flood control. This will almost certainly require that upstream residents and developers bear some of the costs by changing the runoff-increasing potential of their activities.

THE RELATIONSHIP BETWEEN FLOODING AND WATER QUALITY

Point source pollution emanates from stationary, easily identified discharges. Nonpoint source pollution and flooding, on the other hand, arise from a near infinitude of sites. Monitoring of individual sources is impossible in the latter case, implying that the contribution to external costs of each source cannot be measured or identified with much accuracy. In addition, nonpoint pollution has highly variable flows because it is solely a wet-weather problem. During dry weather, runoff into a stream is negligible. But in wet weather nonpoint sources may contribute very high pollution loads. These "shock" loads may be extremely damaging to fish and vegetation. Mitigation measures will be much more complicated for nonpoint sources than for point sources because the runoff pollution problem is related to land use and because monitoring problems make direct regulation of the individual source impossible.

Over 80% of the organic wastes discharged into the nation's watercourses in 1974 was generated by nonpoint sources (Council on Environmental Quality, 1976). Yet, as was noted earlier, virtually all analytic and policy attention has until quite recently been focused on point sources of pollution. This impressive disparity has arisen in part because point sources were easiest to identify and deal with, and in part because conclusive scientific evidence of the importance of nonpoint sources has only recently become available. The relative importance of nonpoint sources has doubtless been enhanced, too, by the rigorous federal controls on point sources. A change in emphasis is now appropriate. Since the marginal costs of point source treatment appear to be steeply increasing (e.g., tertiary treatment of sewage is much more expensive than the presently mandated level of secondary treatment, yet the resulting improvement in water quality is small), further reductions in point source emissions will become increasingly expensive. Since such a high proportion of the remaining water pollution is from nonpoint sources, a sensible pollution control policy must consider the trade-offs between the costs of nonpoint source control and the costs of achieving still more stringent limitations on point source emissions.

How can nonpoint source pollution be controlled most efficiently? Note first that most runoff pollution is, for all practical purposes, an externality problem closely related to the extent of urbanization in a watershed (pollutant loads from undeveloped areas are typically much smaller than those from developed reaches). It is important to separate two kinds of processes by which urbanization affects water quality. First, development increases the speed of runoff as described in the previous section. The faster flow increases the tendency of runoff to pick up pollutants from the ground and reduces the proportion of pollutants picked up that can settle out of the runoff before reaching the receiving watercourse. These effects can be mitigated by changes in land use (retention ponds, green belts, etc.) that slow down the rate of runoff. Controls of this type also provide flood control benefits, a fact crucial to policy formulation as discussed below. Note, though, that it is possible to affect the levels of some pollutants in runoff without changing the pattern of runoff flows produced by a given development. For example, nitrogen concentrations are directly related to the use of fertilizers in the watershed. Accordingly, the amount of nitrogen in runoff could be affected by measures (such as a purchase tax) that reduce the amount of fertilizer used. Under such a program, nitrogen pollution could be reduced without producing any flood control benefits, since runoff patterns would be unaffected.

As we noted above, urbanization generally changes the hydrologic parameters of a watershed so as to produce—jointly and simultaneously—water quality impairment and an increased risk of flooding. An immediate (and until now largely unrecognized) consequence of this joint production is that control measures will also be interdependent. Actions taken to reduce the risk of flood damage will often affect water quality; similarly, programs to control nonpoint source pollution may change the volume and time pattern of runoff, thus affecting the potential for flood damage downstream. More formally, the total benefits to society from a flood control project (B_F) consist of direct flood damage reductions (B_{FF}) plus the benefits (or minus the costs) of any induced change in water quality (B_{PF}). Similarly, the total benefits of a nonpoint source control program (B_P) consist of direct water quality benefits (B_{PP}) and related changes in flood damage due to the program's effects on runoff (B_{FP}). In practice, though, the agency responsible for flood control chooses its policies by comparing B_{FF} and C_F (the cost of flood control), while the agency in charge of water quality evaluates nonpoint source controls by comparing their cost (C_P) with B_{PP}.

Two types of error arise from this simple comparison of the direct benefits and direct costs of each program in isolation. First, the partial equilibrium policy choice will be incorrect; that is, for any given initial level of flood control, the wrong amount of pollution control will be chosen, since the further flood control benefits of pollution control programs are ignored (symmetrically, the wrong amount of flood control will be chosen given any existing level of pollution control). If the policy evaluation were broadened to take into account the indirect benefits of each possible control program, a second error would still remain, since even the correct partial equilibrium analysis does not capture the full extent of interdependence between the flooding and water quality problems. Since, for example, flood control decisions affect pollution levels, they also affect the decision as to how much further withholding of pollution is desirable. The optimal levels of flooding and nonpoint source pollution must therefore be determined simultaneously. Because this is quite difficult to do, the interdependence of the two effects greatly complicates the search for an efficient stormwater management policy.

In sum, an efficient flood control policy cannot be found without considering water quality policies, and vice versa. What we seek is a strategy that maximizes overall net benefits ($B_P + B_F - C_P - C_F$). Optimal levels of flood control and water pollution control cannot be determined separately, especially in a new subdivision where no controls have yet been undertaken. The interdependence between pollution control and flood control, in costs as well as benefits, or in other words, the joint production problem, requires a general equilibrium framework that will determine the optimal amounts of both externalities simultaneously. This rather complicated problem still awaits a formal solution, though we shall be seeking one in the course of our research. For the present, though, a significant improvement in the effectiveness and efficiency of stormwater management policy would result if each proposed policy action were evaluated taking into account its consequences for *both* flood damages and water quality.

THE SCOPE AND NATURE OF EFFECTIVE STORMWATER MANAGEMENT

As we have seen, urban stormwater problems arise in part from the location of human activity in areas subject to flooding from natural causes and in part from the effects of upstream and upland development. It would thus stand to reason that an efficient plan for dealing with these problems would involve attention to both aspects—to the reduction of runoff upstream as well as the prevention of damage downstream. A major reason for the absence of effective stormwater management in American cities is the piecemeal approach to control that has generally prevailed. In this section we will show that effective management requires unified control over an area at least as large as the watershed. We will also discuss some of the policy instruments that might be used by the managing authority.

We have already shown that upstream developers and residents will not find it in their interest to alter their externality-causing behavior voluntarily. How, then, can they be compelled to reduce the impact of their runoff? In most cases, the watershed cuts across several local jurisdictions. The residents of upstream communities have nothing to gain from imposing stormwater controls upon themselves, and the downstream communities lack the legal authority to force them to do so. Acting in their own economic interest, communities have frequently encouraged or required stormwater drainage methods that increase flood hazards to other areas. Conventional curb and gutter street drainage systems and stream channelization are attractive to developers (and to their communities) because, by removing large quantities of runoff from the area quickly, these structural controls decrease flood hazards in their immediate vicinity and increase the amount of developable land there. But fast removal methods significantly increase peak flows, sediment loads, and runoff speeds, thus reducing water quality and increasing flood risks to downstream communities. Individual municipalities and developers have no reason to consider these external costs of their stormwater control methods, but a basin-wide agency concerned with the total costs (external as well as private costs) of stormwater management would have a broader perspective. Basin-wide management thus is the only effective means of insuring that the most cost-effective mix of upstream and downstream controls—considering costs to all occupants of the watershed—will be adopted.

To this point, we have suggested that upstream runoff controls are a necessary component of the most efficient stormwater management plan for an urban watershed. The question remains, how are these controls to be implemented? The remainder of this section explores the nature of efficient runoff control policy.

As we have shown earlier in this paper, the most efficient policy is the one that minimizes the sum of damage and mitigation costs to all affected parties. This optimum is achieved when, on the margin, an additional dollar's worth of mitigation produces just a one dollar reduction in damage costs. In practice, it is difficult to know when the optimum has been reached, since some of the mitigation costs and many of the damage costs are difficult to measure. For this reason, pollution control programs have typically avoided explicit efforts to determine the optimal levels of damage and treatment; instead, a maximum tolerable level of damage (in the form of ambient air or water quality standards) is established, and polluters must reduce their emissions to a degree consistent with achieving the mandated ambient quality standard. Many different techniques can be used to effect the desired reduction in emissions. Given any particular ambient standard, the task of finding the most efficient control policy is relatively straightforward: the policy should result in the standard being met at the lowest total mitigation cost.

Most control measures that have been implemented by governments or suggested in the economic literature on externalities can be classified as prescriptive standards, performance standards, or economic incentives. A prescriptive standard is perhaps the most straightforward in principle: each polluter is told that he must adopt certain specific control techniques (for example, a developer might be required to include a 5-acre retention pond for each 100 acres in his development). Compliance is simple: the required controls must be installed. The government assumes the responsibility for determining which controls will enable the desired ambient standard to be met, and emitters need have no direct concern about the volume of their emissions or the impact of these emissions on the environment so long as the required controls are in place.

In contrast, a performance standard is a requirement that emissions not exceed a specified level (for example, a developer might be required to limit runoff from his land to the amount that occurred before development), with the choice of control techniques left to the regulated firm or individual. In this case, the emitter is concerned with his emission levels since he must find a design that achieves the specified reduction in those levels. Once the performance standard has been met, his interest in emission levels ceases.

Economic incentives offer yet another means for control. Here, the government sets no explicit emission standard, but levies a tax on each unit discharged or pays a subsidy for each unit withheld (for example, developers might be told that they would be taxed a dollar for each thousand cubic feet of runoff expected to flow from their land in an average year). The government would then adjust the tax or subsidy level until the desired ambient standard was met. As with a performance standard, the choice of control technique is up to the developer, but here the developer has a continuing incentive to reduce runoff so long as control measures are cheaper than paying the tax. Companies also have a continuing incentive to find new approaches that lower the cost of control so that they can reduce emissions (and hence their tax bill) as long as they are emitting anything at all.

Economists generally favor the taxation approach on the ground that it is much more likely than either of the standards techniques to meet a given ambient standard at the lowest total social cost (for a survey of the relevant literature see Fischer and Peterson, 1976). The problem with prescriptive standards is that less costly control techniques than those prescribed, no matter how effective, cannot be used. Under such a program, there is little incentive to search for more efficient controls and significant difficulty in introducing them (since the standard would have to be changed). Performance standards are more attractive, since the developer is free to choose the most cost-effective technique he can find, but here too there is little incentive to search for means of reducing runoff further once the standard has been met. Emission taxes provide the greatest incentives for efficiency, in both the present and the future (subsidies create a number of incentives to inefficiency and are thus inferior to taxes as a control measure [Baumol, 1972]). In the case of flooding and pollution problems related to the quantity of runoff from an urbanized area, though, the advantage of taxation over performance standards is less clear-cut. The runoff-generating characteristics of a development (the proportion of impervious surfaces, the drainage system, etc.) are essentially fixed once development is complete, so the tax is quite unlikely to produce further runoff reductions in the future.

A final determinant of the efficient runoff control policy for each community is its location within the watershed, since the magnitude of the external costs to downstream residents from that community's runoff is location-dependent. As it happens, a given amount of runoff from an adjacent development will affect flood risk and water quality much more than will the same amount of runoff from another development further upstream. The longer travel time from the more distant community allows distribution and settling of pollution loads and stretches out the impact on peak flow over a greater time interval. The policy implication of this finding is that runoff controls should be location-specific and should vary in stringency among the communities in a watershed. Watersheds could be divided into zones according to the magnitude of external costs resulting from development at each location. The severity of control (e.g., the rate of a runoff tax) would be greatest in those zones posing high external costs to others, and least in those zones for which development has little potential for inflicting harm elsewhere. (A similar proposal for air pollution control is presented in Tietenberg, 1974.)

We have so far focused on finding the most efficient combination of mitigation actions for the stormwater problems of urban watersheds. Before we conclude this section, a few remarks about who pays for stormwater damage and control are in order.

Consider first a situation in which damages arise only from natural flooding. In this case, treatment consists entirely of protection measures; present victims of flooding receive all the benefits from the protective activities, and no other companies or individuals contribute to the flooding problems of the victims. Accordingly, flood protection should be paid for by the beneficiaries in amounts equal to the benefits they receive. Any other arrangement creates incentives for inefficient development. Suppose, for example, that all residents of the community pay equal shares of the cost. Then those who live in areas subject to little or no damage from flooding are subsidizing their fellow citizens who receive most of the benefits from protection. This subsidy will attract residents to low-lying areas who would not have moved there if taxes were apportioned according to the flood control benefits received.

A similar distortion is introduced if higher levels of government pay some of the costs of flood protection. Here, too, excessive development will take place in flood-prone areas because the residents of these areas will not have to bear the full costs of their location decisions. This effect explains why the drafters of the Flood Disaster Protection Act of 1973 found it necessary to require regulation of floodplain development as a condition for receipt of federal flood disaster relief and federally subsidized flood insurance. Assuming that building in the floodplain does not impose external costs elsewhere, the efficient amount of floodplain development would take place with actuarially fair (unsubsidized) insurance rates and full information about flood hazards even in the absence of direct land use regulation.

If stormwater problems are due in part to the external effects of upstream development, it is appropriate on grounds of both equity and efficiency for upstream residents and developers to bear the costs of control. As we noted earlier, the externality problem arises because those upstream do not face the full costs of their activities. Placing the burden of control upon them eliminates the source of this distortion. But those who generate external costs should not pay for damages due to natural flooding. The latter occur only because downstream residents chose to locate in flood-prone areas.

In summary, a basin-wide management agency is needed if urban stormwater problems are to be dealt with fully and effectively. In general, mitigation of natural flooding should be paid for by those who benefit from the protection program, while the control of externality flooding and water quality problems is properly the responsibility of those generating the externalities. Typically, an efficient management strategy will require both upstream and downstream controls. For the control of runoff upstream, performance standards and runoff taxes appear most likely to encourage the use of cost-effective management practices. In addition, the severity of controls should vary among locations within the watershed.

As a postscript, it is instructive to examine the recent experience of one Texas city to see how difficult it can be to achieve efficient stormwater management. The city's regulations effectively require developers to withhold 100% of the additional runoff generated by development. This policy, by recognizing and dealing directly with the externality component of damages from stormwater runoff, is certainly more enlightened than most. However, two problems appear to have arisen in practice. First, the cost of 100% retention appears to be so high that developers have actively sought alternatives to development in areas subject to this regulation. Second, the city is not able to exercise control over the entire metropolitan area. As a consequence, development has leapfrogged the outer portions of its jurisdiction and continues, essentially unregulated, at more distant sites. What lessons can be learned from this experience? For one thing, it may be that 100% retention is too stringent and costly a control standard given the benefits it provides. Further evidence is needed before a definitive determination can be made in this case, but (as was noted in the introduction) zero discharge is seldom the optimal solution to an externality problem. In addition, the movement of development to unregulated areas (doubtless worsening the stormwater problems in those watersheds) and the resulting urban sprawl demonstrate that stormwater management policy, like many other government actions, can produce unanticipated (and unwanted) byproducts. The experience of this one city suggests that even basin-wide control may be too limited in its geographic scope. Given that development locations can move in response to runoff control policy, region-wide management may be necessary if that policy is to be effective.

CONCLUSIONS

Our economic analysis of urban stormwater problems has a number of important implications for public policy. The following are especially important:

1) Urban flooding and water pollution are in part the direct result of human activity. Accordingly, treatment and mitigation efforts should focus on the source of the problem as well as the site of damage.

2) Control actions should be carried out wherever in the watershed it is most efficient to do so. In no case should treatment be extended beyond the point at which an additional dollar's expenditure on treatment returns just one dollar in benefits from damage reduction.

3) Implementation of an efficient control strategy will in general require basin-wide management, since the extent of the problem is basin-wide.

4) Full social costs, not the apparent costs to particular individuals, firms, or government agencies, should be used as the basis for evaluation of alternative control programs.

5) The pollution and flooding problems are produced jointly, so it will make sense to plan for joint treatment. Water quality improvements arising as byproducts of certain flood control methods should be counted as benefits of these programs (and vice versa).

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